The Magnetic Response of Cuprate Superconductors

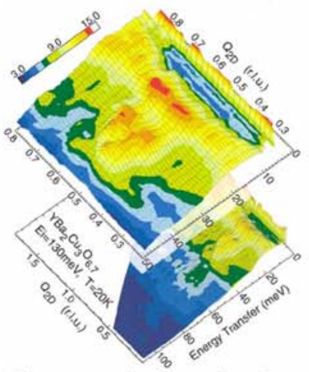
Michael R. Norman
Materials Science Division, Argonne National Laboratory

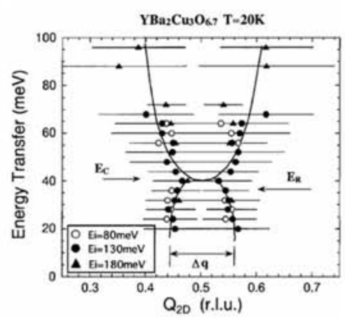
Motivation

Magnetism plays a fundamental role in the cuprate phase diagram. The undoped material is a magnetic insulator. Although long range order is rapidly destroyed with doping, strong magnetic correlations are still present when superconductivity emerges. What role, if any, magnetism plays in the formation of the superconducting state is a much debated topic.

The magnetic response has been determined by inelastic neutron scattering. Improvements in technology have led to a wealth of data, much of this taken by researchers at Brookhaven and Oak Ridge National Laboratories. What they have discovered is that the superconducting phase of the cuprates has an unusual magnetic response, the origin of which is highly controversial. Two pictures have been offered. The one by the Brookhaven group has nothing per se to do with superconductivity. The response rather is proposed to be due to magnetic domains located between rivers of charge (stripes) formed by the doped holes. The other by the Oak Ridge group proposes that the magnetic response is due to the presence of a two dimensional Fermi surface with a d-wave energy gap.

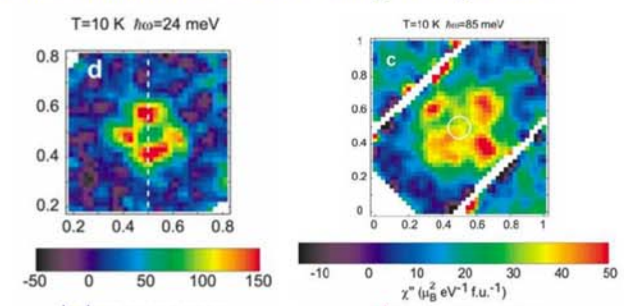
A similar debate has taken place in regards to angle resolved photoemission, infrared conductivity, and scanning tunneling microscopy data. Resolving this debate will be an important milestone towards a solution of the cuprate problem.





The magnetic dispersion in superconducting YBCO has the form of an hourglass. The "neck" of the hourglass is known as the neutron resonance - M. Arai *et al*, PRL 83, 608 (1999)

But the hourglass has a twist!
S. Hayden *et al*, Nature 429, 531 (2004)
The pattern in the Brillouin zone rotates by 45 degrees from bond centered below the resonance energy to diagonal above

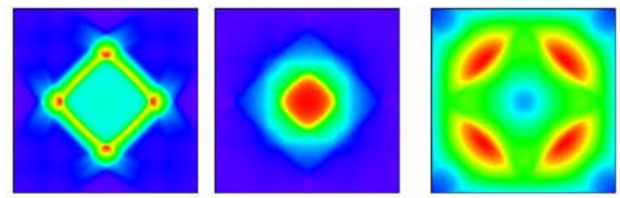


below resonance (24 meV)

above resonance (85 meV)

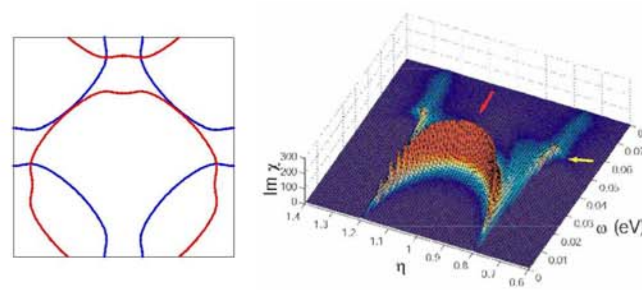
How to Explain It

The picture of the Oak Ridge group was motivated by linear response calculations of the magnetic susceptibility of a d-wave superconductor by myself and others. The single-particle dispersion used in these calculations was based on the angle resolved photoemission data of Juan Carlos Campuzano's group.



below resonance | at resonance | above resonance

These calculations exhibit the observed "hourglass" dispersion, along with the 45 degree "twist" effect. The orientation of the momentum pattern below the resonance energy can be understood as a Fermi surface nesting effect. For the magnetic response, a bond centered wavevector **q** does the best job of bringing the Fermi surface and its **q** translated image into coincidence (left panel):



The pattern above the resonance energy has been discussed extensively by myself and collaborators (Eremin *et al*, PRL 2005) as illustrated in the right panel. We find that the dispersion above the resonance energy is a new collective mode (yellow arrow) whose diagonal orientation is due to the momentum dependence of the particle-hole continuum caused by the d-wave energy gap. This confirms a recent experimental study on optimal doped YBCO by the groups at Saclay and Stuttgart who advocated a similar picture.

Future Directions

Recently, the same magnetic response has been seen in a non-superconducting sample of Ba doped La_2CuO_4 by Tranquada's group at Brookhaven. This indicates that the magnetic response is universal in the cuprates. Finding this behavior in a non-superconducting sample implies that the anisotropic pseudogap must be playing a fundamental role in the magnetic response. The challenge for the future is to incorporate the effect of the pseudogap into our calculations to see whether they can indeed reproduce what was seen by the Brookhaven group.

I. Eremin, D. K. Morr, A. V. Chubukov, K. H. Bennemann, M. R. Norman, Phys. Rev. Lett. 94, 147001 (2005).

This work was supported by the U. S. Department of Energy, Basic Energy Sciences, under contract W-31-109-ENG-38.

ARGONNE NATIONAL LABORATORY | THE UNIVERSITY OF CHICAGO | Office of Science U.S. DEPARTMENT OF ENERGY